

LASER ALIGNMENT DEVICE PROVIDING MULTIPLE REFERENCES

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BACKGROUND OF THE INVENTION

Field of the Invention

The present invention is directed to the field of laser alignment devices.

Description of the Related Art

People undertaking construction and repair projects frequently require the use of reference lines. People employ reference lines on projects ranging from professional construction of large city buildings to amateur home improvement. For example, a person installing a border on the walls of a room requires a level reference line on each wall identifying a placement position for the border.

Traditional alignment tools for assisting in the manual placement of reference lines include straight edges, rulers, protractors, squares, levels, and plumb bobs. More recently, tool manufacturers have introduced laser alignment devices that provide references, such as points, lines, and planes. These laser alignment tools include, simple pointers, pointers with bubble vials, self-leveling pointers, multiple beam pointers, and devices producing a sheet of light.

It is desirable for a single alignment tool to provide multiple types of references, so the number of tools required for a job is reduced. In many instances a project requires the use of multiple references. For example, a project may require the use of reference points, lines, and planes. In many instances this requires the use of multiple alignment tools — forcing a person to have all of these tools available for the project. The purchase, maintenance, storage, and transportation of several alignment tools are undesirable inconveniences that consume time and money. In some

circumstances it is simply impractical to have multiple alignment tools readily available on a job site.

Laser alignment devices could also benefit from improvements in self-leveling. A number of traditional systems employ a single pendulum self-leveling mechanism. In these devices, the single pendulum must provide leveling, while supporting an optical system connected to the device's power supply. This compromises the pendulum's leveling capability — making the design and manufacture of the single pendulum very difficult. Some single pendulum systems require users to manually provide initial leveling settings to reduce the burden on the single pendulum.

Adjusting the position of references in laser alignment devices provides additional challenges. Precise reference location is hard to achieve, due to the inaccuracies of motors used to position optical components. Cogging stiction in the motors inhibits a user's ability to accurately make small adjustments to a reference's location.

Laser beam alignment during device manufacturing also contributes to the difficulty of accurate reference positioning. Manufacturers traditionally mount laser diodes in alignment devices by placing the diode in a cylindrical casing and press fitting the casing into a cylindrical housing. The housing typically aligns the diode's beam with a lens and reflective optical components. Manufacturers make diode alignment adjustments by rotating and sliding the diode's cylindrical casing within the housing. This limits the degrees of adjustment available to alignment device manufacturers.

SUMMARY OF THE INVENTION

The present invention, roughly described, pertains to a laser alignment device that provides reference points, lines, and planes — reducing the number of alignment devices a user needs for a job site. The laser alignment device provides a horizontal set of references and a vertical set of references. For each set of references, users have the ability to select a plane, line, or pointing reference. In one version of the alignment device,

users can also rotate the position of the vertical and horizontal reference points and lines.

The alignment device includes a self-leveling pendulum assembly — eliminating the need for a user to perform manual leveling. The pendulum supports a laser beam source assembly, two laser beam reflectors, and two motors. The laser beam source assembly generates two beams. Each beam is incident on one of the reflectors — producing a horizontal reference beam and a vertical reference beam.

Each reflector is coupled to one of the motors. A motor spins the coupled reflector to generate a reference plane. The motor dithers the coupled reflector to generate a reference line. At rest, the reflector produces a reference point. Each combination of a motor, reflector, and laser beam is aligned perpendicular to the other — causing the reference planes and lines from each combination to be orthogonal to reference planes and lines from the other combination.

The pendulum assembly includes a coarse pendulum and a fine pendulum. The coarse pendulum supports the fine pendulum, as well as the alignment device's rotating motors and beam reflectors. In one version of the alignment device, the coarse pendulum brings the device to within approximately 1-degree of being level. The fine pendulum supports the alignment device's beam source assembly. Without the burden of supporting the motors and reflectors, the fine pendulum brings the device's laser beams precisely to perpendicular and normal positions with respect to the force of gravity.

The laser alignment device also includes a motor control system that enables users to accurately position the device's point and line references. One version of the alignment device employs direct drive motors to rotate the beam reflectors. The pulse width and frequency of motor control signals determine the magnitude of motor rotation. The motors' rotation moves the reflectors to set the position of output reference points and lines.

The motor control system sets the motor control signal frequency and pulse width in response to a user input. The alignment device employs motor characterization data to convert the user's input into a motor signal frequency and pulse width — resulting in a motor rotation that accurately reflects the user's intended magnitude of rotation. The motors' characterization data is obtained during a calibration operation. For user convenience, one method of user input is the time period a user presses a button.

The motor control system also includes a yaw motor to adjust the horizontal position of the alignment device's vertical reference line. An arm containing a friction surface extends downward from a mounting bracket for the pendulum assembly. The arm's friction surface rests against a shaft extending from the yaw motor. When the yaw motor rotates, the shaft's rotation causes the pendulum mounting bracket to pivot — resulting in horizontal movement of the vertical reference line.

Versions of the laser alignment device further include spherical mounting joints for use in the laser beam sources. Laser diodes are mounted in spherical joints that are press fit into orthogonal cylindrical apertures in a mounting block. The spherical surfaces of the joints facilitate precise alignment of the laser diodes — providing more degrees of freedom for adjustment than the traditional solution of cylindrical casings.

Aspects of the present invention can be accomplished using hardware, software, or a combination of both hardware and software. The software used for the present invention is stored on one or more processor readable storage media including hard disk drives, CD-ROMs, DVDs, optical disks, floppy disks, tape drives, RAM, ROM or other suitable storage devices. In alternative embodiments, some or all of the software can be replaced by dedicated hardware including custom integrated circuits, gate arrays, FPGAs, PLDs, and special purpose computers.

These and other objects and advantages of the present invention will appear more clearly from the following description in which the preferred

Figure 14 is a graph representing a pulse width lookup table used during a calibration operation in the reference positioning process in Figures 13a and 13b.

Figure 16 depicts a clutch/release mechanism for use in one version of a laser alignment device.

I. External Operation

Laser alignment device 1 has local user interface 10 and remote control receiver 8. Local interface 10 includes control buttons that enable users to control the operation of alignment device 1 for generating and positioning horizontal and vertical references. Remote control receiver 8 enables communication with a remote control, so a user can remotely direct the operation of alignment device 1. One skilled in the art will recognize that remote control receiver 8 can support any one of a number of different communication mediums and protocols. For example, in one embodiment,

remote control receiver 8 supports radio frequency communication, while in another embodiment receiver 8 supports infrared signaling.

II. Internal Operation

Figures 2a-2f show one implementation of laser alignment device 1 in accordance with the present invention. Figures 2b and 2c show side cross-sectional views from the perspective indicated in Figure 2a. Figures 2e and 2f show front and back cross-sectional views from the perspective indicated in Figure 2d.

Pendulum assembly 20 rests within pendulum mounting bracket 24. Pendulum assembly 20 includes coarse pendulum 26 and fine pendulum 28. Pendulum assembly 20 levels the optical components of alignment device 1, so that vertical output beam 14 is plumb. Magnified views of pendulum assembly 20 appear in Figures 4a-4d, and further details about pendulum assembly 20 appear below.

Laser beam source assembly 30 is mounted on fine pendulum 28, which is mounted on coarse pendulum 26. Laser beam assembly 30 includes mounting block 40, which houses laser diodes 32 and 34 and collimating lenses 36 and 38. Diodes 32 and 34 are mounted so that there beams have an orthogonal relationship to each other and pass through lenses 36 and 38, respectively. Laser beam source assembly 30 is described in greater detail below.

Horizontal beam motor 42 is mounted at the top of coarse pendulum 26, so that motor shaft 46 is aligned with the center of the collimated beam from diode 32. Motor shaft 46 is coupled to mounting structure 50, which holds penta-prism 56. Penta-prism 56 is mounted to receive the collimated laser beam from laser diode 32. Penta-prism 56 bends the collimated laser beam 90-degrees to form horizontal output beam 12.

Alignment device 1 generates horizontal reference planes by spinning penta-prism 56 using motor 42. Alignment device 1 generates horizontal reference lines by dithering penta-prism 56 with motor 42 — motor 42

Vertical beam motor 44 is mounted to the side of coarse pendulum 26, so that motor shaft 48 is aligned along the center of the collimated beam from diode 34. Motor shaft 48 is coupled to mounting structure 52, which holds penta-prism 58. Penta-prism 58 is mounted to receive the collimated laser beam from laser diode 34. Penta-prism 58 bends the beam 90-degrees to form vertical output beam 14.

For adjusting the horizontal position of vertical reference lines, alignment device 1 includes yaw motor 80 and yaw arm 82 (Fig. 2b). As shown in Figures 3a and 3b, yaw arm 82 is mounted to extend downward from pendulum mounting bracket 24. Support member 86 is rigidly mounted to housing 22. Pendulum mounting bracket 24 is attached to support member 86 at point 88 to pivot about point 88. In one implementation, bracket 24 is attached to member 86 at point 88 using saddle joints. Support member 86 includes tab 90, which rests in notch 92 of pendulum mounting bracket 24.

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Alignment device 1 damps the motion of pendulum assembly 20 to aid pendulum assembly 20 in coming to rest and remaining at rest. In one implementation, alignment device 1 implements magnetic damping with magnets 64, 66, 68, and 70. In alternate implementations of device 1, different damping mechanisms are employed, such as fluid or air damping.

III. Pendulum Assembly

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approximately 1-degree of being level. After the coarse leveling of pendulum 26, fine pendulum 28 only has a relatively small leveling burden to resolve to bring pendulum assembly 20 to a level position.

Figures 4a-4d provide views of dual pendulum assembly 20, as explained above with respect to Figures 2a-2f. Figures 5a-5d provide views of coarse pendulum 26, and Figures 6a-6d provide views of fine pendulum 28. Coarse pendulum 26 includes arms 103 and 104 terminating in base 60. Fine pendulum 28 includes arms 120 and 122 terminating in base 62. Fine pendulum arms 120 and 122 swing within coarse pendulum arms 103 and 104.

As shown in Figures 4a, 4b, 5a, and 5b, coarse pendulum 26 rests on notches 94 and 96 of mounting bracket 24. Coarse pendulum includes tabs 100 and 102 resting in notches 94 and 96, respectively. Coarse pendulum 26 swings about an imaginary axis extending between tab 100 and tab 102. The contact radius for the tab-notch combination is the distance the axis of rotation is offset from the tips of tabs 100 and 102.

As shown in Figure 5d, coarse pendulum 26 includes fine pendulum gimbal ring 106. Figures 6a and 6b show corresponding gimbal ring 108 on small pendulum 28. Gimbal ring 108 includes rods 110 and 112, which are rigidly mounted within corresponding holes (not shown) in gimbal ring 106 of coarse pendulum 26.

Figures 6a and 6b also show mounting posts 114 and 116 extending through gimbal ring 108. Posts 114 and 116 secure fine pendulum arms 122 and 120, respectively, to gimbal ring 108. Posts 114 and 116 secure arms 122 and 120 so that fine pendulum 28 swings within coarse pendulum 26 along an imaginary axis extending between posts 114 and 116. In one implementation, coarse pendulum 26 and fine pendulum 28 are aligned so their respective swing axes are perpendicular to each other. Additionally, the pendulums' swing axes go through a point of coincidence with the beams from laser beam source assembly 30.

Gimbal ring 108 on small pendulum 28 (Figs. 6a and 6b) also supports laser beam mounting block 40, which houses diodes 32 and 34 and lenses 36 and 38. Gimbal ring 108 has openings 128 and 130 to pass beams from diodes 34 and 32, respectively. Gimbal ring 106 has corresponding openings (not shown). Gimbal ring 108 is aligned within gimbal ring 106 in coarse pendulum 26, so that a beam passing through opening 128 is incident in penta-prism 58 and a beam passing through opening 130 is incident on penta-prism 56.

Fine pendulum 28 also includes a mechanism for adjusting the center of gravity for pendulum assembly 20. Member 113 is mounted to pendulum arms 120 and 122. Member 113 is tubular with external and internal surfaces that are threaded. Weight 115 has an internal threaded surface and is positioned on member 113. A set screw (not shown) is positioned inside member 113. Adjusting the position of weight 115 and the set screw shift the center of gravity for pendulum assembly 20. Adjusting the set screw provides fine adjustments, while adjusting weight 115 provides course adjustments.

IV. Laser Beam Source Assembly

Figure 7 shows a magnified cross-sectional view of laser beam source assembly 30. Mounting block 40 includes cylindrical openings 138 and 140 for receiving and holding laser diodes 34 and 32, respectively. Collimating lens 38 is mounted directly across from opening 138, and collimating lens 36 is mounted directly across from opening 140. Collimating beams from lenses 38 and 36 exit assembly 30 through exits 144 and 142, respectively.

In one embodiment, lenses 38 and 36 are mounted so their centers are offset from the center of the beams produced by diodes 34 and 32, respectively. In such an embodiment, lenses 38 and 36 are mounted to rotate about an axis passing through the center of the beams from diodes 34 and 32, respectively. This allows the positions of lenses 38 and 36 to be

adjusted to bring the beams from diodes 34 and 32 into an orthogonal relationship.

Laser diodes 32 and 34 are coupled to circuit boards 132 and 130, respectively, to receive power. Spherical mounting joint 134 holds laser diode 34 for placement in opening 138. Spherical mounting joint 136 holds laser diode 32 for placement in opening 140. Spherical mounting joints 134 and 136 are press fit into openings 138 and 140, respectively. Spherical mounting joints 134 and 136 have a spherical surface on front sections 146 and 148, which are inserted into openings 138 and 140. Spherical sections 146 and 148 allow manufacturers to tilt mounting joints 134 and 136 within openings 138 and 140. In alternate implementations, sections 146 and 148 have rounded surfaces that may not be a perfect cross-section from a sphere.

The ability to tilt joints 134 and 136 provides greater flexibility in aligning diodes 32 and 34 with lenses 36 and 38, respectively. Manufacturers press fit and adjust mounting joints 134 and 136 so the beams from diodes 34 and 32 are perpendicular after passing through collimating lenses 38 and 36, respectively. In some implementations, manufacturers apply glue or epoxy to further secure the positioning of joints 134 and 136.

Figures 8a-8e show spherical mounting joint 134 and apply equally to joint 136. Spherical mounting joint 134 includes spherical front section 146 for press fitting into a mounting block opening. In one version, front section 146 has a rounded surface that spherically curves as the surface extends away from face 150. Chamfer 152 extends from face 150 to inner surface 151 of joint 134. Chamfer 152 acts as a guide for press fitting diode 34 into joint 134. Diode 34 is press fit into joint 134 so that the diode's beam is coincident with the center of the sphere of which section 146 is a portion. Face 154 contains an opening for allowing the electrical leads from a laser diode to exit joint 134.

In one version, joint 134 has a press fit interference of .001 to .003 inch with mounting block opening 138.

Figure 9 shows a cross sectional view of an alternate version of laser beam source assembly 30. The laser beam source assembly in Figure 9 uses laser diodes 172 and 174 to generate horizontal and vertical laser beams. Split-block flexure 170 includes hollow channels 175 and 177, which are orthogonal to each other. Laser diode 172 is mounted at one end of channel 177 along with collimating lens 178. The laser beam from diode 172 passes through collimating lens 78 and exits block 70 as a collimated beam through channel 177. Laser diode 174 is mounted at one end of channel 175 along with collimating lens 176. The laser beam from diode 174 passes through collimating lens 176 and exits block 170 as a collimated beam through channel 175.

In order to ensure that the horizontal and vertical beams are perpendicular to each other, block 170 includes adjustment screws 180 and 182. Block 170 is made of aluminum, plastic, or any other strong, yet moderately flexible material. Block 170 is substantially split along diagonal 184 — providing a small degree of play between the opposing sides. Screw 180 extends into the portion of block 170 housing diode 174 from the side of block 170 housing diode 172 and through the split along diagonal 184. Screw 182 extends into the portion of block 170 housing diode 174 from the side of block 170 housing diode 172 and through the split along diagonal 184. Screws 180 and 182 hold block 170 together in a rigid position. The positions of diodes 172 and 174 are adjusted to ensure their orthogonal relationship to each other by tightening or loosening screws 180 and 182.

Figure 10 shows a cross-sectional view of a yet another version of laser beam source assembly 30. The laser beam source assembly in Figure 10 divides the beam from a single laser diode to generate two orthogonal laser beams. Block 190 includes channel 193 extending along the diagonal of block 190. Laser diode 192 is mounted at one end of channel 193. Collimating lens 194 is mounted in channel 193 in front of diode 192. Beam dividing mechanism 196 is mounted in channel 193 to receive a collimated beam from diode 192 through lens 194.

In one embodiment of the present invention, beam dividing mechanism 196 is a bi-mirror machined from aluminum or a similar reflective surface. Bi-mirror surfaces 198 and 199 each present an angle to the collimated beam from diode 192 and lens 194. The angles of surfaces 198 and 199 are set so that bi-mirror 196 splits the incoming beam into two perpendicular beams.

Block 190 also includes channels 195 and 197 — each extending from a respective face of bi-mirror 196 to the exterior of block 190. Channels 195 and 197 are formed to be perpendicular to each other. As a result, resulting orthogonal beams from bi-mirror 196 pass through channels 195 and 197 to form horizontal and vertical beams.

In alternate embodiments of the laser beam source assembly shown in Figure 10, different mechanisms can be employed to divide the beam from laser diode 192. For example, a pair of mirrors or beam-splitters can replace bi-mirror 196. The mirrors or splitters are aligned orthogonal with each other to form a knife-edge, with each surface at a 45-degree angle to the incoming collimated beam. In another implementation, a single laser diode directs a beam onto a beam splitter to create two orthogonal beams.

V. Laser Beam Reflection

Figure 11 illustrates a five-sided prism that can be employed to operate as penta-prisms 56 and 58. Figure 11 is described with reference to penta-prism 56, but the description is equally applicable to penta-prism 58. Penta-prism 56 produces an output beam perpendicular to a beam entering through input side 202. In operation, beam 210 enters penta-prism 56 through side 202 and is reflected by mirrored surface 204 to produce reflected beam 212. Mirrored surface 206 reflects beam 212 to create perpendicular horizontal output beam 12.

In an alternate version of penta-prism 56, surface 204 is a beam splitter that reflects and transmits beam 210, and a wedge of glass is mounted on the outside of beam splitter 204. As a result, a plumb beam is

generated along with horizontal output beam 12. In a further modification, penta-prism 56 is mounted so that it can be rotated out of the path of beam 210 — allowing a plumb beam output to be generated. In other implementations, penta-prisms 56 and 58 are each replaced by a single mirror or set of mirrors for bending beam 210.

VI. Alignment Device Control Subsystem

A. Architectural Overview

Figure 12 is a block diagram of laser alignment device 1 — including control subsystem 224, output beam subsystem 222, yaw motor interface 234, horizontal beam motor interface 236, vertical beam motor interface 238, local user interface 10, and remote user interface 220.

Output beam subsystem 222 includes the components described above with reference to Figures 2a-2f for providing references from vertical output beam 14 and horizontal output beam 12. As explained above, output beam subsystem 222 includes horizontal beam motor 43, vertical beam motor 44, and yaw motor 80.

Control subsystem 224 controls user interfaces to laser alignment device 1 and the operation of motors in output beam subsystem 222. Control subsystem 224 includes bus 232 coupling controller 228, data storage unit 226, memory 230, and input/output block 244. Controller 228 is a central processing unit used for executing program code instructions, such as a microprocessor or microcontroller. In response to program code instructions, controller 228 retrieves and processes data and provides data and control signals. Input/output block 244, data storage unit 226 and memory 230 are all coupled to bus 232 to exchange data and control signals with controller 228.

Memory 230 stores, in part, data and instructions for execution by controller 228. If a process is wholly or partially implemented in software, memory 230 may store the executable instructions for implementing the process when laser alignment device 1 is in operation. Memory 230 may

include banks of dynamic random access memory, static random access memory, read-only memory and other well known memory components

Data storage unit 226 provides non-volatile storage for data and instructions for use by controller 228. In software embodiments of the present invention, data storage unit 226 may store instructions executed by controller 228 to perform processes. Data storage unit 226 may support portable storage mediums, fixed storage mediums or both

Data storage unit 226 implements fixed storage mediums using a magnetic disk drive or an optical disk drive. Data storage unit 226 supports portable storage mediums by providing a portable storage medium drive that operates in conjunction with portable non-volatile storage mediums — enabling the input and output of data and code to and from control subsystem 224. Examples of portable storage mediums include floppy disks, compact disc read only memory, or an integrated circuit non-volatile memory adapter (i.e. PC-MCIA adapter). In one embodiment, instructions for enabling control subsystem 224 to execute processes are stored on a portable medium and input to control subsystem 224 via a portable storage medium drive.

For purposes of simplicity, all components in control subsystem 224 are shown as being connected via bus 232. Control subsystem 224, however, may be connected through one or more data transport mechanisms. For example, controller 228 and memory 230 may be connected via a local microprocessor bus, and data storage unit 226 and input/output block 244 may be connected via one or more input/output (I/O) busses.

Input/output ports 246, 248, and 250 in input/output block 244 couple bus 232 to yaw motor interface 234, horizontal beam motor interface 236, and vertical beam motor interface 238, respectively. Yaw motor interface 234 is coupled to yaw motor 80 in output beam subsystem 222. Horizontal beam motor interface 236 is coupled to horizontal beam motor 42 in output beam subsystem 222. Vertical beam motor interface 238 is coupled to

vertical beam motor 44 in output beam subsystem 222. Motor interfaces 234, 236, and 238 provide conversions between the digital data and control signaling of control subsystem 224 and the analog signaling of the motors in output beam subsystem 222.

Input/output ports 252 and 254 in input/output block 244 couple bus 232 to user interfaces 10 and 8. Input/output port 252 is coupled to local user interface 10. Input/output port 256 is coupled to remote user interface 8. Local user interface 10 provides a portion of the user interface for a user of laser alignment device 1 to control the operation of device 1. In different implementations, local user interface 10 may include an alphanumeric keypad or cursor control device, such as a mouse, trackball, stylus, or cursor direction keys. Information provided by the user through local user interface 10 is provided to controller 228 through input/output port 252.

Remote user interface 8 enables a user to communicate with laser alignment device 1 using remote control 221 — allowing the user to provide instructions. Remote user interface 8 supports the protocol required for facilitating a communications link with remote control 221 — providing conversions between the digital signaling of control subsystem 224 and the signaling of remote control 221. For example, one type of remote control communicates with remote user interface 8 through a radio frequency connection. Another type of remote control communicates with remote user interface 8 via an infrared signaling connection.

U.S. Patent No. 5,680,208 and U.S. Patent No. 5,903,345 provide examples of remote controls and remote control interfaces that can be used with alignment device 1. U.S. Patent No. 5,680,208 and U.S. Patent No. 5,903,345 are hereby incorporated by reference.

In addition to the above-described components, control subsystem 224 may include a display system and a communications controller. A display system enables laser alignment device 1 to display textual and graphical information. The display system may include a cathode ray tube (CRT) display or liquid crystal display (LCD). The display system would

receive textual and graphical information from controller 228 through input/output block 244. Potential communications controllers include network interface cards or integrated circuits for interfacing alignment device 1 to a communications network. Instructions for enabling control subsystem 224 to perform processes may be down loaded into memory 230 over the communications network.

Those skilled in the art will recognize that Figure 12 only shows one embodiment of control subsystem 224 and that numerous variations of control subsystem 224 fall within the scope of the present invention. The components contained in control subsystem 224 are those typically found in general purpose computer systems, and in fact, these components are intended to represent a broad category of such computer components that are well known in the art.

B. Positioning Horizontal References

Operators select the location of horizontal reference lines and points by providing a location input through remote control 221 or local user interface 10 — causing horizontal beam motor 42 to rotate penta-prism 56 into a desired position for a reference point or line. Laser alignment device 1 includes a motor control mechanism that enables operators to accurately position horizontal beam motor 42 when selecting reference line and point locations. In one implementation, motor 42 is a direct drive motor, such as the motors used in compact disc players.

Figure 13a shows a process employed by laser alignment device 1 to position horizontal beam motor 42. Device 1 controls horizontal beam motor 42 by providing a control signal. The pulse width and frequency of the control signal determine the magnitude of rotation of horizontal beam motor 42. Horizontal beam motor 42 is first calibrated to identify an ideal pulse width for use in positioning motor 42 (step 260). Next, device 1 determines the motor control signal necessary for positioning motor 42 to a desired position (step 262) and provides the signal to motor 42 (step 264).

Figure 13b provides a more detailed view of the process shown in Figure 13a. In the calibration process, the motor control signal pulse width and frequency are set to predetermined values, such as 1,000 microseconds and 200 hertz (steps 266 and 268, respectively). An encoder is coupled to motor 42 in the calibration process. The encoder includes alternating transparent and blacked-out elements. In one embodiment, each element represents one degree of a 360-degree circular encoder. The motor is rotated a predetermined number of degrees—90 degrees in one implementation. Device 1 records the number of pulses required to move through each encoder element during the rotation (step 272). Device 1 then calculates the average number of pulses required to pass through an encoder element (step 274).

Next, device 1 determines the ideal pulse width (PW_{ideal}), based on the average number of pulses per encoder element (step 276). Figure 14 shows a graphical representation of a lookup table employed in one version of device 1 to determine the ideal pulse width. Device 1 identifies the ideal pulse width in the lookup table that corresponds to the average number of pulses per encoder calculated in step 274. In one version of the lookup table, the values for the ideal pulse width are rounded to the nearest 25 microseconds and the values for the average number of pulses per encoder has a range from 2 to 20.

The above-described calibration process can be performed either during the manufacturing process for laser alignment device 1 or as part of normal device operation.

After calibration, device 1 retrieves a positioning input for horizontal beam motor 42 (step 278) — indicating the distance motor 42 is to be rotated. One method of obtaining this input is determining the time period that an operator presses a button on remote control 221 or local user interface 10. Device 1 employs the positioning input to determine the frequency (step 280) and pulse width (step 282) for the motor control signal.

In one implementation of device 1, the pulse width and frequency are obtained from lookup tables characterizing horizontal beam motor 42. Figure 15a depict a graphical representation of a frequency lookup table for motor 42. The frequency values are obtained, based on the following equation:

$$\text{Frequency} = \text{Minimum}([K_0 * 10^T], [f_{\max}])$$

wherein:

Frequency is the motor control signal frequency.

Minimum() means the minimum value between the parentheses.

$$K_0 = 10^{\text{Log}(f_{\max}) - IC_1}$$

f_{\max} is the maximum motor control signal frequency.

IC_1 is the time at which f_{\max} occurs.

T is the time duration the operator provides the positioning input.

Figure 15b depicts a graphical representation of a pulse width lookup table for motor 42. The pulse width values are obtained, based on the following equation:

If T is less than or equal to IC_1 :

$$PW = PW_{\text{ideal}}$$

If T is greater than IC_1 :

$$PW = \text{Minimum}([\text{Slope} * (T - IC_1) + PW_{\text{ideal}}], [PW_{\max}])$$

wherein:

PW is the motor control signal pulse width.

$$\text{Slope} = (PW_{\max} - PW_{\text{ideal}})/(IC_2 - IC_1)$$

PW_{\max} is the maximum motor control signal pulse width.

IC_2 is the time at which PW_{\max} occurs.

In an alternate embodiment, alignment device 1 calculates the motor signal frequency and pulse width in real-time, instead of using lookup tables.

In further implementations of alignment device 1, a clutch/release mechanism holds motor 42 in place once positioning is complete. The clutch/release mechanism also provides a constant physical drag force to motor 42—swamping the variable magnetic drag of motor 42. During the positioning of reference points, the drag aids by smoothing out the number of pulses required to move through each encoder element.

The pivot assembly supporting pad 292 includes arm 294 coupled to pivot point 296 and arm 298 coupled to pivot point 296. Arm 298 supports weight 300. Clutch/release 290 also employs spring 302, which is mounted between shaft 46 and arm 298. Spring 302 pulls arm 298 towards shaft 46 — holding pad 292 against the base of motor 42. As motor 42 rotates, shaft 46 rotates — creating a centrifugal force that causes the pivot assembly to pivot about point 296. Once the rotation of shaft 46 exceeds a predetermined speed, the resulting centrifugal force pulls pad 292 completely away from motor 42. In practice, pad 292 is not in contact with motor 292 while reference planes are provided, and pad 292 is positioned to provide friction during the generation and positioning of reference lines and points.

C. Positioning Vertical References

Vertical beam motor 44 (Figures 2a-2f) operates in the manner described above for horizontal beam motor 42 to generate vertical reference points, lines, and planes. Vertical beam motor 44, however, cannot adjust the horizontal position of a vertical reference line. Device 1 adjusts the horizontal placement of a vertical reference line using yaw motor 80, as described above. Control subsystem 224 directs the positioning of vertical beam motor 44 and yaw motor 80 in response to user inputs from remote control 221 or local user interface 10, as described above for horizontal beam motor 44. In one embodiment, vertical beam motor 44 is also a direct drive motor like the motors used in compact disc players and is positioned using the process explained above with reference to Figures 13a-16.

As an alternative to yaw motor 80, some versions of laser alignment device 1 include a rotary base. In such embodiments, housing 22 is mounted to the rotary base. In response to user input from local user interface 10 or remote control 221, control subsystem 224 causes a motor in the rotary base to rotate housing 22. Alternatively, a motor in housing 22 causes housing 22 to rotate about the base. U.S. Patent No. 5,680,208 provides examples of a rotary base solution for use in a laser alignment device.

The foregoing detailed description of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. The described embodiments were chosen in order to best explain the principles of the invention and its practical application to thereby enable others skilled in the art to best utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the claims appended hereto.